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An end effector based on the Bernoulli principle for handling sliced fruit and vegetables

S. Davis*, J.O. Gray, Darwin G. Caldwell

Centre for Robotics and Automation, University of Salford, Manchester M5 4WT, UK

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Abstract

This paper describes the design and testing of a gripper developed for the handling of delicate sliced fruit and vegetable products commonly found in the food industry. The device operates on the Bernoulli principle whereby air flow over the surface of an object generates a lift. The gripper allows objects to be lifted with minimal contact thereby reducing the chances of damaging or contaminating the object. The paper will describe the mathematical basis of the gripper operation followed by tests showing the nature of the grasp.

As a secondary benefit it will be shown that the flow of air over the object can also be used to remove surface moisture produced during slicing. This drying effect is a feature particularly useful in some areas of food production.

The paper will show a test manufacturing cell demonstrating the placement of slices of tomatoes and cucumber on to sandwiches.

Keywords: End effector; Gripper; Non-contact; Bernoulli effect; Food; Tomato; Cucumber

1. Introduction

Food and drink manufacturing forms one of the largest global industry sectors. In the EU alone the industry has a turnover of €600 billion and employs 2.5 million people [1]. It has for over a decade been identified as a major growth area for the application of automation systems with the aims of [1]:

- improving production efficiency;
- enhancing hygiene standards;
- improving working conditions;
- impacting on yield margins and profitability;
- conforming to existing and future legislation pertaining to food production.

Yet inspite of these driving influences only a small number of companies make significant use of automation for raw and in-progress product handling.

Although limited use of automation is certainly a reflection of conservative investment policy in a low margin industry, in many instances the use of labour intensive manual techniques is a deliberate policy. This is due to the flexibility provided by the human worker and the perceived in-abilities of current automation systems, particularly the capacity to handle and manipulate food products.

This need for flexibility and scepticism with regard to automated handling is strongly influenced by the nature of the food product which is in many instances non-rigid, often delicate and/or perishable and variable in texture, colour, shape and sizes. The consequence is that the food product inherently deforms significantly during handling.

Clearly the nature of many food products means that the handling, characteristics cannot be adequately described in a conventional geometry based manner since their geometry is often a function of time and the forces applied to the object. Any systems developed to handle food therefore need to react accordingly to this deformation. Humans handle these complexities with ease by combining dextrous handling capabilities (human hand) and behavioural models of the product accumulated with experience.

*Corresponding author.
E-mail addresses: s.davis@salford.ac.uk (S. Davis), j.o.gray@salford.ac.uk (J.O. Gray), d.g.caldwell@salford.ac.uk (D.G. Caldwell).

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In this paper one of the most difficult situations is approached, this is the handling of freshly sliced fruit and vegetable products specifically tomato and cucumber. The paper describes the development of a Bernoulli based end effector for the handling of soft flexible foodstuffs. It begins by examining grippers developed for handling non-rigid food products. This is followed by a study of how such products, particularly tomato and cucumber slices, are currently handled. Section 4 describes the development of a Bernoulli principle gripper and this is followed by a section that compares experimental results with modelled performance. The gripper has the secondary benefit of being able to dry the object it is handling and this is explored in Section 6. Section 7 demonstrates the effectiveness of the gripper through the development of a robot cell. Section 8 highlights the benefits of the gripper developed and finally conclusions are presented.

2. Grippers for non-rigid food products

The majority of food products are non-rigid and vary enormously in size, shape, texture and colour. As a result it is often not possible to handle food products using traditional techniques and this has led to the development of a number of novel approaches. Taylor [2] classifies the main techniques for gripping non-rigid material into three classes.

Mechanical surface—here the material is clamped or pinched between gripper fingers to give high frictional holding. Items such as fish and poultry can be handled using a clamping type gripper with the gripper surface being angled to mechanically lock slippery items in place. A compliant interface rubber or foam may be added to the gripper to prevent bruising when grasping fruits and vegetables.

Intrusive—here pins are fed into the surface or body of the material and moved to lock it into place. This type of gripper is generally unsuitable for food products as it would cause unacceptable damage.

Surface attraction—this includes the use of adhesives or vacuum. Vacuum grippers which employ suction cups can be used to grip food items. However, not all food items can be handled with such grippers as the vacuum nozzle can become clogged with dirt or scraps of materials and this can be a source of bacterial contamination or cross product contamination. This type of gripper is commonly used in the harvesting of fruits where the surface being gripped is relatively hard and yet easily bruised.

The highly variable nature of food products means that there have also been a number of other approaches which broadly fit into the three classes outlined above.

Stephen and Selinger [3] developed a "freezing gripper" where grip is attained by rapidly freezing water vapours that have been distributed on the gripping spot. The freezing element (Peltier Heatpump) can, it is claimed, produce a grip surface temperature of $-10\,^{\circ}\mathrm{C}$ within 1 s of contact. To release the material, the frozen vapour is liquefied by slightly warmed air. Although this gripper was developed for the textile industry it may have great potential in the food industry especially for example in the packaging of frozen food items.

Electrostatic grippers using a high voltage field to create an adhesive effect have also been developed to handle textiles and leather. Although the grip forces are small it is possible that this method could be applied to handling of thin delicate strip materials e.g. smoked salmon.

Erzincanli et al. [4] developed a non-contact robotic handling system for non-rigid materials. This was a surface attraction technique based on air outflow not suction. The end effector consists of radial air flow nozzles that generate high speed air flow between the nozzle head and the material surface, thereby creating a vacuum which lifts the product. The clearance gap of the nozzle must be very small compared with the diameter of the central supply tube for an attractive force to be generated. The high outflow rates from the nozzle mean that this method is not suited to handling of delicate products that would be destroyed by the air flow.

Further detail of the handling of non-rigid materials can be found in the work of Saadat and Nan [5] which presented an overall picture of recent research into the automatic manipulation of flexible materials.

3. Tomato and cucumber handling

Within the food manufacturing and assembly industry the placement of freshly sliced products, particularly vegetables, is common. Within the UK sandwich industry, which has an annual turnover of over £4 billion, tomatoes and cucumbers are the most common ingredient. However, they are notoriously difficult to handle and as a result their placement during sandwich assembly is always performed manually.

Typically fresh vegetables such as tomatoes and cucumbers are washed and sliced in a secondary part of a factory using large scale slicing machines capable of processing many kilos per minute. Once sliced the product is deposited into trays, Fig. 1, for delivery to the lines.

The high water content of most vegetables and the nature of the cutting means that slices have a high residual moisture on their surfaces and cannot be placed directly onto sandwiches without making the bread soggy. This reduces the appeal to the customer although it has no significant environmental issues. To reduce this "sogginess" and improve shelf life the sliced vegetable trays are left to drain, for at least 2 h, before being used. The effectiveness of this method is highly variable, with the upper layers of ingredients draining more thoroughly than those towards the middle or bottom of the tray.

After draining the trays are delivered to the assembly lines where operators pick individual slices from the trays and place them on the sandwiches, Fig. 2. It is extremely difficult to do this without further damaging the slices and as a result it is not uncommon for the centre of tomatoes to